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measurement systems laboratory

massachusetts institute of technology, cambridge massachusetts 02139

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MULTISPECTRAL AND THERMAL SCANNER EXPERIMENTS ALONG THE MASSACHUSETTS COASTLINE

Final Report, NAS 12-2213, April 1970

by

A. C. Conrad

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A. C. Conrod

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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MULTI-SPECTRAL AND THERMAL SCANNER EXEPRIMENTS ALONG THE MASSACHUSETTS COASTLINE

Final Report

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ABSTRACT

Multi-spectral imagery was obtained for several coastal and other sites in Eastern Massachusetts in the Spring and Summer of 1969. Color aerial photography and thermal infra-red imagery was obtained for some of the sites simultaneously with the multi-spectral imagery. Results of the experiments are reported for a thermal mapper survey of Boston Harbor; photographic, multi-spectral and thermal images of Plum Island, Massachusetts, and multi-spectral coverage of a dye-tracing test outside of Boston Harbor.

The report is without illustrations but the location of the original imagery is given.

I. INTRODUCTION

The Measurement Systems Laboratory of the Massachusetts Institute of Technology has been involved in a National Aeronautics and Space Administration's Electronics Research Center Program on data handling and data management for Earth Surveys. As part of their work, NASA-ERC arranged a demonstration experiment in New England to provide a focus for their internal efforts on data handling. The services of the Bendix Corporation's multi-spectral and thermal infra-red scanner were procured, to obtain aerial coverage of sites that were selected by MIT-MSL. Our laboratory's role in the experiments, as stated in our proposal and the statement of work, was to

> Determine and specify to ERC and Bendix Aerospace Systems Division the best flight lines and times of flights in the Massachusetts Bay-Boston Harbor area,
>
> Recommend best calibration setting for the nine-channel multispectral scanner, thermal IR mapper and sequential photographic camera,
>
> Organize and direct the surface environmental ground truth data taking teams,
>
> Conduct chemical and physical analyses of water samples,
>
> Correlate ground truth data with aerial multispectral imagery data,
>
> Perform assessments of multi-spectral imagery in satisfying user information requirements for applications of coastal surveying, fisheries and pollution monitoring, and,
>
> Recommend data analysis and image processing techniques which should be considered by ERC in utilizing these experimental data in research on automated information systems.

At the beginning of the program, we approached a number of organizations and people in the New England area who might have an interest in aerial coverage of sites in Eastern Massachusetts, and would therefore be interested in assisting by suggesting sites, participating in ground survey work, and offering analyses and opinions on the data, in exchange for unrestricted access to the raw data and some influence in the test site location. The names of the persons approached, and the cooperating participants, are contained in the appendices.

The persons outside of M.I.T. filled the role of "data users"; that community of natural scientists, engineers, government investigators and administrators, and commercial interests, who will, presumably, be the people for whom the Earth Survey program will be conducted. We attempted to select sites and design experiments related to real problems, that would be representative of some situations that one would expect to encounter in an operational Earth Survey system; one, incidentally, employing ground teams and aircraft as well as satellites. Individual survey goals are described under the site characteristics and mission summaries, in following sections.

All of the sites were coastal areas, except for two overland lines selected for geology and land use applications. The problems being considered were primarily related to pollution and coastal processes. Since these are frequently local phenomena, and often involve rapid spatial change over relatively small (i.e.,<0.1 KM) distance, aircraft methods had to be considered as well as satellite observation schemes, in considering user requirements.

Some comments should be made in this introduction on the subjects of scale, ground resolution, and the repetition rate of remote sensing for near-shore and coastal waters. Local tidal conditions, offshore currents, and local weather and climate, all affect the kind and rate of coastal processes. New York, New England, and Northern Europe, for example, experience relatively large tidal excursions on their coasts and, in consequence, considerable volume flow and tidal mixing. Most run off and tidally-induced suspended and dissolved matter is carried off by long-shore transport mechanisms, but the dominant local influence is the once or twice daily tidal flow. Other areas, such as the Mediterranean Sea or upper Chesapeake Bay, do not have tides of importance, so the dominant method of transport is in land run off and river outflow patterns, and ocean currents. These may be influenced by seasonal conditions, especially storms, but probably do not undergo regular daily variations. In either case, small scale phenomena may be important, and since they may be ephemeral where large tides exist, tides impose different requirements for their measurement.

When coastal waters and estuaries are subjected to significant tidal action, the requirements of an observation system are rather obvious; observations will have to be made on a once per tide cycle basis, or more often, for continuously monitoring conditions in those areas, and ground resolution will have to be relatively high. When one considers the repetition rate (between successive nadir points)

for the ERTS satellite series, and the resolution figures for the ERTS sensors, then it would seem that airplanes will be the primary vehicle for some coastal surveillance tasks for some time to come. Satellite systems of the 1970's will be most useful for large area experiments, or in areas where strong tidal action does not exist, and consequently where rapid temporal change is not expected, and in those places the ERTS vehicles may have a role in actual, operational problems, ground resolution permitting. In these areas too, though, the airplane will play an important role in remote sensing in the years immediately ahead.

Another vital area in remote sensing programs for this or any other kind of target site is the final disposition and use of the data. The problems that will be caused by the volume of data from satellite systems is being considered elsewhere, so the comments here will have only to do with the problems of data distribution, the degree of data processing required, and the probable format of processed data as it is handed to the ultimate user. Only general statements can be made in this introduction but other comments are included in following sections where appropriate.

At the Federal government level, and in large private scientific and commercial groups, the size of the organizations would permit assignment or recruitment of suitably trained personnel to use and interpret remote sensing data, where in fact such people are not already available. Users at other levels, though, such as offices in state and local governments, and smaller commercial companies, laboratories, and universities, will often need data interpretation assistance. These last may eventually make up well over half of the user community for Earth Survey data, and if that is so the success of the program may depend on how effective the data processing and distribution functions are.

One immediate reaction of many of the state, local, and private interest representatives with whom we have spoken deserves mention. Most had reservations about performing any work of the kind presented to them with their own internal funding, even where they thought the data might be useful. The reasons given usually fell into one or

more of the following categories: the expense of having the work done by their own people, or by a commercial firm, was felt to be too high for the value received, as they perceived the value; they did not understand the rudiments of the technology involved and were uncertain as to how they would use the data and had no means of becoming trained or of hiring trained personnel so that they could exploit the techniques; or, they would be unwilling to support work when they did not have the expertise to oversee and supervise it.

If the scope of the investigation had been wider so that some data processing work could have been performed, the reactions might have been somewhat different, but probably not much because the cost and the means would still have been beyond the capacities of all but one or two of the organizations, chiefly Federal government laboratories who helped with or observed the experiments.

The Commonwealth of Massachusetts has procured some limited aerial photographic and infra-red imagery in the past, for evaluation of remote sensing for specific purposes; sewage outfalls and thermal pollution. Otherwise, almost everyone contacted during the program has adopted an attitude of waiting for the development of a national program, from which they would expect raw and processed data to be provided with at least a partial subsidization of the costs involved. None of the persons contacted said they had no further interest in remote sensing data.

II. DESCRIPTION OF EXPERIMENTAL PROGRAM

Three series of flights were made by the Bendix Corporation's aircraft during the program, on April 22 thru 26, on June 11 and 12, and again on August 18 to 21, 1969.

The April mission was curtailed by weather problems, but some data was obtained on a dye drop experiment, and some coastal areas were covered. Only multi-spectral scanner data were acquired, since both the aerial camera and the thermal mapper were inoperative. The mission logs are contained in Bendix Report BSR 2864 and show the de-

tails of all flights.

1. April Tests

Since the aborted experiments planned for April were successfully repeated in June or August, only the dye drop will be mentioned now. The discussions of the coastal images obtained in April will be mentioned with the August experiments, except for one line which covered the Salem-Manchester, Massachusetts area. The dye experiment had two objectives:

1) to determine the utility of multi-spectral scanner data for dye tracing in relatively turbid waters, and,
2) to collect information related to diffusion and dispersion of a known quantity of dye injected at the site of proposed combination sanitary and storm sewer outfall diffuser field.

As stated in the introduction, the cooperation of outside organizations was sought, both in defining operationally significant goals for the experiments and in assisting in the work. During the dye tracing experiment we had the advice and assistance of the Federal Water Pollution Control Administration's New England offices, and in particular of their Northeast Water Quality Management Center. We were also assisted by the Commonwealth of Massachusetts' Department of Natural Resources, Division of Water Pollution Control. Both agencies provided boats, personnel, and services during the test. Sea-surface temperature and BT data were taken by the crew of the USCG lightship "Boston", through the courtesy of the commander, 1st Coast Guard District. Bottom drifters were also put overboard from the "Boston". The bathythermographs and the bottom drifters were supplied by Dean F. Bumpus, of the Woods Hole Oceanographic Institution.

The dye drop as indicated by the boat's log, was made at 0830, approximately 10 miles at sea. Two hundred and fifty pounds of Rhodamine Base BT-liquid dye was used. The dye has a peak absorption wavelength of 556 nM. and a peak florescence wavelength of 583 nM. These are within channels 3 and 4 of the EMSIDE scanner, respectively, and in fact the 583 nM florescence peak is very nearly the center of channel 4 (590 nM).

Conditions recorded on the boat at the time of the drop were; sea state 1, wind West at 2 to 5 knots, water temperature 5°C at the surface. The "Boston" recorded 3.8°C water temperatures from the surface to the bottom. The boat was about 3 to 5 miles north of the "Boston" during the tests. Usable images of the dye patch were obtained about one and three hours after insertion. Afternoon flights recorded no useful data. Strongest images were found, as expected, in channel 4, but channel 1, the near-u.v., also gave some readings. The most interesting feature was the discrepancy between the map of the dye patch, after three hours, and the imagery. The people on the boat were all experienced in dye tracing, and had a florimeter for in situ measurement of dye concentrations. They produced a map showing an elongated mile long patch heading north of the drop point. The imagery showed in addition, a long area of low dye concentration, extending - "feathering" might be a better word - to about a mile and a half to the east, and covering two or three square miles. That down wind drift was not observed by the boat crew.

Another image of interest was made just south of Cape Ann, Massachusetts, at 1515 hours. The flight passed over an outfall of the Salem-Beverly sewer system. The outfall has a mean flow of 18 m.g.d., of untreated sewage. Previous color and color infra-red photographs of this area showed the plume to be detectable, but it was not as clear as the images in channels 2 and 4 of the EMSIDE. The coincidence of the green and blue-u.v. images will be investigated further in the future.

2. June Tests

On June 11th night flights were made over Boston Harbor, to obtain thermal infra-red coverage of the harbor waters. The primary goal of the experiment was to attempt the location of outfalls, which would be identifiable on an i.r. record from either a temperature or emissivity difference. The experiment was run with the cooperation of Prof. Ralph Cross, M.I.T. Civil Engineering Department, Mr. Myron Knudson of FWQA, and John Elwood of the Mass. Department of Natural Resources. On their advice, the experiments were scheduled to coincide with slack water periods.

The first line of the flights was flown over the harbor entrance and successive lines were run to the westward. As the images showed, some ebb flow was in evidence throughout the flights.

The imagery was excellent, and a wealth of detail is visible, even on half-tone illustrations. Among the most noteworthy features, in addition to the surface current patterns visible throughout the harbor, are the surface patterns in the water at the North ends of lines 3 and 4, and the hot water at the south end of lines 5 through 7. The surface patterns in the harbor, near the airport are probably evidence of films of pollutants, most probably oil and grease. The differences of tone would then be ascribed to a difference in emissivity, rather than temperature. There is a definite relation between harbor industrial land use and darker mottled and striated tones on the images of the water. Unfortunately, this must remain speculation for the time being since no boats were available to provide "ground truth" assistance for the experiments. In defense of the supposition, though, there are no large volume, cold-flow outfalls in the inner harbor that are sufficient to cool surface water by about 2 or 3°C, which would be the only other explanation for the observed image tones.

The current patterns in the harbor did not agree completely with the USC and GS harbor current chart. Since wind and sea state were essentially calm, surface and sub-surface flow were probably similar, suggesting that the current charts may be in some error.

Curiously, little obvious evidence of unknown outfalls was seen (this was one of the goals of the test), though a few were observed. It is possible that the time of the flights may have influenced this, as there are not many three-shift industries in the Boston area, and there had been no rainfall locally for several days. The experience of municipal sanitary workers shows that there is low flow between about 11:30 PM and 6:00 AM, with two peaks, one about 1:00 AM and a lesser one about 3:00 AM. The flights fell in between these two peaks, which also helps to account for the fact that no unrecorded outfalls were seen. (Boston's municipal and other facilities date back to the 1800's and complete maps and records do not exist. Local workers are fairly sure that there are unknown active outfalls, and possibly some spills and leaks from charted drain lines.)

3. August Tests

The August flights were concentrated about Plum Island, Massachusetts, and Plum Island Sound. Lines were also flown inland, as far as Worcester, Mass. Those experiments will not be mentioned in this note, except to state that geological data were collected for J. S. Skehan, S.J., of Boston College, and R. Simpson, Dartmouth College.

Inquiries on results should be directed to them, at the addresses shown in the appendix.

The Plum Island flights covered the island, the sound and its adjacent salt marshes, and a portion of Cape Ann, Mass. The region had been surveyed and described previously, by W.C. Jerome et al, of the Mass. Division of Marine fisheries. A surficial geology map, GQ-189, exists for a portion of the area covered in the flights. During the planning and execution of the tests, we had the advice and assistance of Prof. M. Hayes, Mr. S. Farrell and Miss S. Greer of the U. of Mass. Geology Department.

Small boat and shore transects were run. Observations agreed with previous surface surveys of the island and sound, both of which are contained by a Federal Wildlife Refuge, and hence relatively immune to gross disturbance. Water sample analyses compared with Jerome's 1967-68 data in all parameters measured. We did not do any bathymetry on the ocean side of Plum Island, but did record depths, and bottom sampling, inside the sound.

Simultaneous Ektachrome MS, EMSIDE, and thermal mapper data were obtained on all lines. Virtually all of the imagery was good-to-excellent, and contained considerable information.

The EMSIDE images of the coastal vegetation showed tonal patterns whose boundaries were very close to the soil classifications of the surficial geology map GQ-189. In other areas of the site, good correspondence existed between the images and "ground truth" data taken in transects of the island and sound. It is hoped that some EMSIDE taped data can be processed in the future, to investigate antomatic extraction of soil and plant information, and water depths, from the August coverage. As nearly as the eye can judge from prints of EMSIDE and thermal mapper images, good results should derive from such work.

One feature that seemed evident on visual examination was a difference in tone and density between images of certain plants in the sound, with its fairly good water quality, and the same wetland plants growing in the estuary of the industrial, heavily polluted, Merrimack River, just north of Plum Island. This has suggested some experiments that should be tried at the first opportunity.

APPENDIX

The following are names, affiliations, and addresses of persons who took part in the tests, and who are now in possession of prints of the data. The list is given to allow interested persons to contact them directly for information on their uses, and assessment, of the images. It is also to identify them for the sincere appreciation of the writer, NASA-ERC, and Bendix Aerospace, for their assistance and advice.

Mr. Myron Knudson
Mr. David Stonefield
Federal Water Quality Administration
240 Highland Ave.
Needham Hts., Mass.

p.r. data, Boston Harbor

Prof. Ralph Cross
M.I.T., Dept. of Civil Engineering
Cambridge, Mass. 02139

i.r. data, Boston Harbor

James S. Skehan, S.J.
Department of Environmental Science
Boston College
Chestnut Hill, Mass

overland M.S. & photos, Worcester, Mass. to coast.

Robert O. Simpson
Geography Dept.
Dartmouth College
Hanover, N.H.

overland M.S. & i.r. data, urban areas, E. Mass.

Mr. John Elwood
Department of Natural Resources
State Office Bldg.
Boston, Mass.

color, M.S. and i.r., Plum Island and Boston

Prof. M. Hayes
Geology Dept.
Univ. of Mass.
Amherst, Mass.

color, M.S. and i.r., Plum Island

Other copies of images may be examined, as mentioned earlier, at D.O.T.-T.S.C., Cambridge, Mass. (Mr. M. Miller) and Bendix Aerospace, Ann Arbor, Mich. (Mr. D. Hanson).